GEOLOGICAL RESEARCHES IN YUCATAN.

BY PROF. ANGELO HEILPRIN.

The observations recorded in the following pages were made in the early spring of 1890 in the course of the explorations by the Expedition organized under the auspices of the Academy of Natural Sciences. The points of investigation are included between Progreso on the northern coast, the cave-region of Calcehtok (in the first range of hills) on the southwest, Labna on the south, Tunkas (on the Valladolid road) on the east, and the Port of Silam (Silam). So far as I know, no critical examination of the geological features of any portion of this region, or indeed, of any part of Yucatan, had been made prior to our visit. Unfortunately, want of time did not permit us to penetrate beyond the range of mountains (Sierra de Yucatan) above referred to, but from information received from various sources and from the general lay of the land, I am led to believe that much or most of the region beyond possesses the same general geognostic features as those which characterize the country traversed by us.

Of the few travelers who have succeeded in penetrating into the deep interior of Yucatan, there is scarcely one who has given even as much as a hint of the geology of the country; but more surprising yet, even the geography of the region is unknown. The traveler has but to consult the latest maps of the peninsula, official and unofficial, to see how varied a course might be picked out between almost any two points that are somewhat removed from one another. A direct course of 40–50 miles may differ, according to the maps used, by fully 10 or 20 degrees of the compass; mountain chains may have to be crossed or not, just as it suits the convenience of the traveler in his choice. Lakes appear in one chart, and they are replaced by water-courses in another; or both are entirely wanting in a third. Towns and roads appear where, in reality, there is but a wilderness, with possibly a traversing mule or deer path. Even the principal range of hills, that which runs in a N. W.—S. E. line from beyond Ticul in the direction of Peto, and culminates in an elevation of approximately 900 feet,[1] is wholly

[1] Determined barometrically by Mr. Edward H. Thompson, U. S. Consul at Merida; the position of this most elevated point is not far from Xul, a few leagues southeast of Labna.

omitted from some maps, while it is deflected at a right angle on other maps; again, the chain frequently appears supplemented or replaced by a S. W.—N. E. chain terminating at, or passing, Valladolid. It is difficult to account for these geographical aberrations. The map accompanying Stephens' work (1843) is in a general way accurate—much more so than most recent maps—and the position of the principal mountain mass is given in its nearly true points. That remarkably accurate observer also omits the non-existent rivers and lakes, making exception, however, in favor of the actually existing lake (southeast of Peto) of Chichenkanab.

Our scanty knowledge of the interior of Yucatan is doubtless due in principal part to the difficulty (or assumed difficulty) of penetrating into the region of the revolted Mayas. It is currently believed that no white man, except at extreme risk to his life, can penetrate into the interior either from the west or from the north; but the experience of Consul Thompson, as proved by his travels, shows that good judgment and a knowledge of the Maya language may effectually protect a non-Mexican from the dangers of assault which are certainly intended to be directed solely against the Mexicans and their supporters—in other words, against those to whom the revolted Indians decline to recognize allegiance. The so-called "wild" Indians of the interior are, in fact, identical with the Mayas of the north, and in their behavior to strangers, except to Mexicans, they are as peacefully inclined as are their (supposed) more highly civilized brethren of the north. Hence, it is not difficult to enter their country from the side of the British possessions, *i. e.*, from Balize. It is from that side that Dr. Gaumer, the well-known collector of birds (now a resident of Izamal), and his wife penetrated.

First after Stephens to make an extended tour through Yucatan was Captain Lindesay Brine, R. N., who, in the early part of 1870 (January 30th to April 8th) traversed the region from Guatemala to Sisal. A brief account of this journey, entitled "On the Ruined Cities of Central America," is published in the Journal of the Royal Geographical Society for 1872 (vol. XLII). No geological facts are given in this paper, but there is a suggestive reference to the conservative or preservative character of the climate, which may have some bearing upon the determination of age of the prehistoric ruins. It has been urged, and seemingly with much force, by those who uphold the comparatively recent construction of these buildings, that the sharp arêtes or cornices which still ornament the exterior

walls cannot be of great antiquity, since continued exposure to atmospheric influences would in a comparatively brief period turn rounded edges and corners. In examining the walls of Uxmal I was especially struck with the knife-edges which mark long courses of marble, as straight and clean as though they had been laid in our own generation. I was immediately impressed with this circumstance as strong evidence tending against great antiquity. But in the light of what Captain Brine says, I am not sure that this evidence of itself carries much weight. Thus, it is asserted by this traveler, that he "found the names of Stephens, and Catherwood, and Pawling, which were written apparently with a bit of charred wood on the inner surface of the entrance archway [at Palenque], as fresh as when first done in 1840"—*i. e.*, thirty years previous. This is certainly a most extraordinary instance of resistance to atmospheric influences.

Of the very few references touching the physiography of Yucatan, the most important are contained in a paper by Dr. Arthur Schott on the coast formation of the north, published in Petermann's Mittheilungen for 1866.[1] In this paper the author discusses the nature of the long sea-dam (sand and shell dune) which skirts the coast for a length of some 170 miles, and of the brackish water-strip or lagoon which it encloses. The double formation is attributed to the antagonistic effects of the sea and of the subterranean (or submarine) outflows (of fresh water) from the land; the sea-dam is normally broken at but two or three points throughout its course, the breaks occurring in positions—as opposite the estuary of the so-called Rio Lagartos—where the terrestrial waters emerge with sufficient force, or have accumulated in sufficient volume, to overcome the oceanic pressure from the outside. Dr. Schott incidentally refers to the condition of the interior "cenotes" or sinks, whose universality throughout the region is recognized, and remarks that inasmuch as the level of the water in these is approximately that of the sea (varying two or three inches toward the close of the rainy season), the depth of the cenotes must in itself be an index of the elevation of the land surrounding them (the elevation increasing as we recede from the sea). Thus, it is held that in, and immediately about, the capital city, Merida, the cenotes have a depth of from 26–28 feet; at some little distance south of the city, 30 feet; half

[1] Die Küstenbildung des nördlichen Yukatan.

way between Merida and the north coast, 12–15 feet, and at Progreso, on the coast, 0.

I determined the depth of the cenotes about Merida and found it to be approximately as stated by Schott. But it is beyond question that the water-level in the cenotes generally, except possibly in the case of a few that are not very distantly removed from the sea, has no connection with the level of the sea. This is shown by the condition of the aguadas, or larger basins, where the level of the water is far from constant, and varies within very broad limits. The same condition is illustrated by some of the deeper caves, such as Bolonchen, for example, in which frequently no water of accumulation is met with until a level seemingly considerably below that of the sea is reached.[1]

In any consideration of the geognostic features of Yucatan, three distinct regions of the country must be recognized: the lowland plains, the mountains (perhaps more properly designated hills), and the submerged plateau which gradually shelves into the Gulf and is known as the Yucatan Bank. The last, in whatever way it be considered, is, it appears to me, geologically a part of the continental area.

The lowland plains, lying north of the Sierra de Yucatan, rise gradually as we proceed inland from the coast-border at the rate, perhaps, of a foot or a foot and a half per mile, which is, of course, considerably less than the pitch of the sea-floor immediately north or west of the peninsula. But in this feeble rise of the land we have no positive indication that it is the normal of elevation, as denudation has doubtless done something to level the country since its emergence from the sea. But from such stratigraphical correlation as we found possible to make, it would seem that the leveling has been insignificant, and perhaps not sufficient to materially alter an

[1] Stephens gives the depth to which he descended in the cave of Bolonchen as approximately 450 feet ("Incidents of Travel in Yucatan," II, p. 152, 1843). Unfortunately, there are no data at hand for determining the elevation of Bolonchen itself, but inasmuch as the town lies considerably to the south of the Sierra, on the north-and-south line of Ticul, and as the absolute elevation of the Sierra itself is here only about 450 feet, as we determined by means of a very sensitive aneroid barometer, the position cannot be more than 100–200 feet above the sea, if it is that much. The elevation of Ticul, which lies at the north foot of the Sierra, is, as I am informed by Señor Antonio Fejardo (a long-time resident of the town), approximately 90 feet. Probably the elevation of Bolonchen does not differ greatly from that of this town. It would thus seem that there has been here considerable subsidence since the formation of the cave.

original relief. At the present time the absence of running streams would naturally largely check surface degradation, but, on the other hand, an equivalent in part would be obtained from the sinking of the floor over the numerous limestone caverns with which the country abounds. At Merida, some 23 miles from the north coast, the general elevation is about 28–30 feet above the sea, at Ticul about 80–90 feet, and at a point on the Merida-Sotuta railroad, one-half mile east of Tekanto, 42 feet.[1] A line drawn from Progreso to the crest of the hills immediately south of Ticul would give a gradient approximately equal to that of a line of similar length projected northward from Progreso over the submerged plateau.

The rock formation over the greater part of the plains is that of a gray or white shell limestone, highly indurated or sub-crystalline in local areas, but rarely to the extent of obliterating its fossiliferous character. Secondary depositions of calcite, in the form of veins, crystals and nodular masses, are abundant. Where less compact the rock may be said to be a mass of loosely-united shells, a condition that is best shown in the superficial layers. Good sections of the rock are seen only in the walls of the aguadas and cenotes and in a number of railway cuts which traverse it both in a N.—S. and E.—W. line; the rock surface is, however, visible over a very large part of its extent, being but scantly covered with soil and supporting only an indifferent vegetation. Its decomposition has liberated large quantities of red earth, similar to that which is found in our own northern region (*terra rossa*) and on coral islands (*e. g.*, the Bermudas, Bahamas), and which is seemingly a residual product representing impurities of one form or another which were introduced into the limestone at the time of its formation. The great quantity of this impurity, which constitutes much or most of the soil of the country, taken in conjunction with the circumstance that the limestone is of shallow-water formation, suggests the notion that this iron-impurity is a product of the volcanic discharges which for a long period of time visited the region, and must have contributed a vast amount of oxydizable material to that which was slowly accumulating through the agency of organic forces in the Gulf basin. The surface of the limestone is eaten out into irregular knolls and hollows, which become more pronounced as we move inland from the northern coast.

[1] As determined by railroad levelings conducted by Colonel John W. Glenn.

The paleontological evidence of the fossils contained in the limestone is to the effect that the latter belongs to two periods of geological time, the Pliocene and the Post-Pliocene, but stratigraphically it is not easy to draw a line of demarkation between the two formations. It, indeed, appears as though the Post-Pliocene, except in the coastal area, were present only in patches, having been removed through atmospheric decay and denudation. It is in most places easily distinguished by the large numbers of *Venus cancellata* which fill the rock, making a true *Venus cancellata* bed, such as I observed capping the Pliocene beds on the Caloosahatchie, Florida, just below Fort Thompson. The beds occupy similar positions and hold equivalent relations to the construction of the land, and may, therefore, be considered as counterparts of an identical formation. At Fort Thompson the *Venus* bed is found at an elevation of some 24 feet above the sea, a few feet less, perhaps, than the level which the same bed holds in the exposed walls of the cenotes at Merida. At the railroad station of San Ignacio, about half way between Merida and Progreso, the same bed has fallen to a level of about 14 feet; it is there crowded with the shells of its distinctive fossil, one of the most abundant of the Gulf Mollusca. We found the same fossil equally abundant on the roadway between Kansakhab and Oilam, at points 12–15 miles or less from the coast, and not unlikely this whole northern slope between the coast and some fifteen miles inland is a Post-Pliocene surface. The low exposures, however, do not make this absolutely clear, nor do they permit us to say just how much further the same deposits extend. Post-Pliocene cappings continue at least as far as Merida, and not improbably outcrops will be found much further in the interior. But as has before been remarked, the close connection existing between the Post-Pliocene and Pliocene deposits does not permit a sharp differentiation of the two series. At first glance, indeed, I assumed that the whole northern plain was a recent formation, but a closer examination of the fossil remains leaves no doubt that the major formation is the Pliocene, which is here and there covered or obscured by more recent deposits.

My examination of the Pliocene area was made at several points in and about Merida, in numerous cuttings along the line of the Merida-Kalkini Railroad, on the line of the railroad connecting the capital city with Ticul, all along the traverse between Merida and Tunkas—some twenty miles E. S. E. of Izamal—and

at various points between Tekanto and Oilam. The rock-formation over all this area is largely uniform, and shows frequent recurrence of the same fossils; there is no question, therefore, of its identity throughout. I enjoyed special advantages for studying fresh material in the cutting which was being made at the time of our visit eastward of Tekanto, in the railroad section connecting this town with Izamal.[1]

The following is a list of the fossils that I have thus far been able to identify from the rocks of this formation; the species preceded by an asterisk are non-living or Pliocene forms, the remainder live in the adjacent seas.

From the R. R. cutting (Camp Glenn) one and a half miles east of Tekanto:

Pecten nucleus.
Pecten n. sp.
Anomia simplex? (**A. Ruffini?*)
Plicatula filamentosa.
Lucina reticulata.
Arca Adamsi.
Venus mercenaria.
Venus cancellata.
Marginella apicina?
**Turritella perattenuata.*
**Turritella apicalis.*
Bulla striata.

From a rock outcrop west of Izamal:

**Amussium Mortoni.*

From the cenotes near Merida:

**Pecten* n. sp.
Pecten nucleus (*dislocatus*).
Cardium isocardia.
Venus Listeri.
Venus cancellata.

From a railroad cutting about half-way between Merida and Ticul:

Pecten nucleus.
Pecten sp. indet.
Pinna sp. indet.
Lucina Jamaicensis.
Lucina edentula.
Cardium magnum?
Cardium muricatum?
Venus mercenaria.
Murex Salleanus?

From a digging in the city of Merida:

**Ostrea meridionalis.*
Anomia simplex.
Pecten nucleus.
**Amussium Mortoni.*
Plicatula filamentosa.
Arca Deshayesii.

[1] The writer is under great obligation to Colonel John W. Glenn, Engineer of this section of the Merida-Sotuta Railway, and to Mrs. Glenn for many facilities afforded the exploring party toward the prosecution of their work, and for the comforts of a railroad "camp" during a period of nearly two weeks.

**Arca* sp. indet.—Very close to *A. incongrua* and *A. scalarina* (from the Pliocene of Florida), but differing in the greater width of the ribs and in the absence of the intercostal line. The specimens are in the form of impressions and do not permit of characterization.

Arca rhombea.

**Pectunculus* sp. indet.—Seemingly different from any of the living species.

Lucina tigrina.
**Lucina disciformis.*
Lucina Pennsylvanica.
Cardium serratum.
Cardium muricatum.
Cardium isocardia?
Chama arcinella.
Venus mercenaria.
Venus Mortoni.
Artemis discus.
Macoma contracta.
Tellina sp.?
**Fulgur rapum.*
Dolium perdix.
Oliva literata.
Cypræa sp. indet.
Pyrula reticularis.
Siliquaria sp. indet.

Fulgur rapum, Turritella perattenuata, T. apicalis, Ostrea meridionalis and *Lucina disciformis* are forms which I have previously described from the Pliocene deposits (the "Floridian") of the Caloosahatchie.[1] *Amussium Mortoni*, also found in the Caloosahatchie deposits, is a well-known fossil of the Carolinian Miocene, and represents the recent *A.* (*Pleuronectes*) *Japonica* (from which it differs mainly in the disposition of the interior ribs). Besides the species above enumerated, the rocks in nearly all cases—at least, when they are largely fossiliferous—contain almost numberless impressions of a *Venus*, so far as I know, not now living, whose nearest analogue appears to be *Venus cribraria* of Conrad, a Miocene species of the Atlantic border of the United States.

The exact position in the Pliocene series which these Yucatan rocks hold cannot, perhaps, be stated, but they with little doubt, correspond at least in part with the series occurring in Florida which I have designated the "Floridian." It is true that the number of extinct species of the mollusks is seemingly less in the Yucatan rock than in that of Florida, but it should be said that in addition to the forms above enumerated, there are a considerable number, occurring mainly in the condition of unrecognizable casts, which may largely represent extinct species. The number of corals

[1] "Explorations on the West Coast of Florida and in the Okeechobee Wilderness."—Trans. Wagner Free Institute of Science, vol. 1, Phila., 1887.

found associated with the molluscan remains was exceedingly limited; indeed, it was only after long search that I detected their existence at all. I picked out a good-sized clump of *Porites* from a cutting on the Merida–Ticul railroad, and found a few simple corals elsewhere. They represent only a sporadic growth, and I could nowhere determine any evidences of reef-structure.

The Mountain Region.

The rock-formation of the Sierra de Yucatan differs in many particulars from that of the basal plain. The surface rock, forming the crest and the slopes on either side—presumably an anticlinal structure—is a fairly compact red or reddish limestone, which seems to rest at nearly all places, as we had occasion to observe in the caves of Calcehtok and Loltun, on a semi-crystalline white or gray marble or on an exceedingly fine grained cream limestone, somewhat resembling in texture true lithographic stone. A brecciated limestone, containing fragments of the last mentioned rock, occurs at intervals along the base of the hills, and we also found it among the rocks used in the construction of the buildings (now ruins) of Labna. I am not absolutely certain as to the age or even as to the general nature of the red-rock. The brecciated masses are almost undoubtedly of marine origin, and they give evidence of the encroaches of the sea after the underlying rock had not only been formed but been converted into its present semi-crystalline condition. In other words, the present range of hills probably by that time already existed. It is, however, less clear that the red or reddish rock which extends away from the base of the hills, but forms their slopes, is of marine origin. Its universality would seem to indicate that it was of this nature, but at many places where I examined it, on and off the crests of the hills, it bore suspicious marks of being a disintegration product, which had subsequently undergone cementation. The only fossil that I found in it, on any surface exposure, was a *Helix* (probably identical with a species now living in the same region), which was obtained from near the summit of the pass between Ticul and Santa Elena, at an absolute elevation of perhaps 300 feet. It occurred in a thoroughly hard rock, but this circumstance is in itself no proof of actual antiquity, since in a purely calcareous region such as this one, rock cementation is a rapid process, as we had occasion to observe in the terrestrial (fossiliferous) limestone now forming near a quarry about two

miles south of Ticul. In the red rock which in the cave of Calcehtok overlies the gray limestone I found the impression of a single gasteropod, which I should unhesitatingly refer to a terrestrial form, and to a genus of *Pupidae* close to *Macroceramus*, if indeed, it is not *Macroceramus* itself.[1] I could find no vestiges of marine mollusks, but yet they may well occur in other parts of the rock, and it would, perhaps, not be safe to conclude that the entire red-rock is of terrestrial origin, or that it represents a single type of formation.

No doubt attaches to the heavily-bedded gray and white limestones and marbles which are so well exhibited in some of the deeper caves, such as that of Calcehtok, for example. The mouth of this cave, according to a rough approximation, is some 200 feet above the sea.[2] At a depth of some 50 feet the red limestone appears in a solid mass, and beneath it we reach the crystalline limestones, which are disposed in layers of 10–15 feet thickness. Fossils are not abundant in this rock, and Col. Glenn, who had explored this cave on a previous occasion, was of the opinion that no fossils were to be found in it. After considerable search, however, we discovered a few in an indifferent state of preservation, and still later some whose characters were sufficiently defined to permit us to determine their relationship. Among these are a *Pecten*, with little doubt *Pecten nucleus*, the cast of a large *Marginella*, apparently the living *Marginella labiata*, a *Potamides* or *Cerithidea*, the impression of the apex of a large Oliva (of the type of *Oliva literata*), and a single impression of *Venus cancellata*. While the above forms are barely sufficient to determine the exact age of the formation in which they occur, whether Pliocene or Miocene, I am inclined to believe that it is rather the former, the mountain-rock—semi-crystalline or highly compact, and but scantily fossiliferous—being a compressional alteration of the much less compact and highly fossiliferous rock of the basal plains. But whether Pliocene or Miocene, I think it can be all but positively assumed that it is not older than Miocene, although it has been asserted that it represented the Oligocene or Vicksburgian period.[3]

[1] Mr. H. A. Pilsbry, Conservator of the Conchological Section of the Academy of Natural Sciences, has kindly directed my attention to this relationship.

[2] The height of the pass leading to the cave we determined barometrically to be about 250 feet above the hacienda of Señor Escalante (situated at the north oot of the mountains), which is itself elevated some 60 feet. The total height of the pass is thus somewhat above 300 feet.

[3] Alexander Agassiz—"Three Cruises of the Blake," 1, p. 69.

The cave itself is a magnificent specimen of subterranean architecture and in several of its features far surpasses the Luray Caverns. The broad entering arch, a feature which we found repeated in the scarcely less imposing cave of Loltun, in the mountains southeast of Ticul (or the hacienda of Tabi), is in striking contrast to the contracted passage which leads into the famous cavern of Virginia. Huge stalactites hang from heights of 50–70 feet or more, or unite with stalagmites to form continuous columns of giant proportions. Many of these measure as much as six or eight feet in diameter, and some of them considerably more. In the cave of Loltun we measured one which was thirty-six feet in circumference about five feet above its base, and I am certain that there are others that are still larger, both here and in the cave of Calcehtok. The chambers, especially in the last named, are imposing in their dimensions, and communicate with one another by the usual clefts and narrows. There is little moisture in either of the caves; most of the chambers are thoroughly dry, and they have accumulated extensive deposits of disintegrated rock material. In the short time at our command we could not explore the caves to their furthest limits, but we saw enough to convince us that their extent was quite considerable. We descended in the cave of Calcehtok to a depth of approximately 170 feet, or to within about 30 feet of the level of the sea; unfortunately a shortage of illuminating material, and the disinclination of the Mayas to proceed further, prevented us from prosecuting our search to the end that we should have desired. The red rock which we found superimposed upon the gray limestones in the cave of Calcehtok reappears in the cave of Loltun, where, however, we failed to find the underlying older stratum. This was probably due in part to the stalagmitic crust with which much of the surface was covered, and to the circumstance that this cave is much less deep—at least in the part traversed by us—than the cave of Calcehtok.

We found among the ruins of Labna that much of the stone that was used by the ancient Mayas in the construction of their habitations was the semi-crystalline limestone, and not the surface rock that is found in the region. The builders had manifestly brought their rock from some distance, but from what special locality I could not determine. This preference for a particular building stone is also seen in a number of small ruins traversed by the railroad about two miles north of Ticul. The material there used is also a very compact gray limestone, but it differs from the limestone of the cave in

being highly fossiliferous, and in lacking the subcrystalline structure of the latter. The fossils are unfortunately in too imperfect a condition to be satisfactorily determined, but they are in part crowded with an orbicular Foraminifer, or rather, its impressions, which measure about a third of an inch in diameter. From the form of the impressions, I should say that the Foraminifer is a *Patellina* (*Cyclolina*). Whence this rock was obtained I know not, but it certainly differs from the field rock which appears a short distance from the ruins.

The heights determined by us on the Sierra are the following: the summit of the pass leading over from the hacienda of Señor Escalante (near Calcehtok) 250 feet, or 310 feet, approximately, above the level of the sea; the summit of the pass leading over from Ticul to Tabi, 300 feet above Ticul, or 390 feet approximate absolute elevation; summit of the pass leading over from the hacienda of San Juan to Uxmal, 160 feet above the plain. At all of these points the hills rise fully 50 to 75 feet, or more, above the highest point reached by us; accordingly, the hills immediately south of Ticul cannot be much less than 500 feet in elevation. But as has already been said, the range further to the southeast attains 900 feet. The range itself is composite in structure, having two or three parallel lines of elevation which include longitudinal valleys.

The Yucatan Bank.

Little positive can at the present time be said regarding the structure of the Yucatan Bank. It is well known that Alexander Agassiz, who is almost the only authority that has critically touched the history of the Gulf basin, considers it, in common with the similar formation lying to the west of the peninsula of Florida, to have been formed through a process of slow organic accretion—the accumulation, through an undefined period of time, of animal debris upon an early fold (or bank) of the earth's crust—in which the force of elevation has practically played no part.[1] I have in another place discussed the probability of this view, and have stated that I could find no satisfactory evidence in support of it—on the contrary, almost the only positive data that we possess in the premises argues

[1] Three Cruises of the Blake, chapter III, vol. 1, on "The Florida Reefs;" "Coral Reefs of the Hawaiian Islands," Bull. Mus. Comp. Zoology, XVII, April, 1889; and elsewhere.

directly against it.[1] Apart from the non-evidence we have in the matter of giant limestone banks being built up from deep water in a comparatively brief period of geological time, the position of the Pliocene and Post-Pliocene deposits in both Florida and Yucatan shows that there has been a comparatively recent uplift, and for anything that I know to the contrary, this uplift may have been quite modern, and might, indeed, be progressing to-day. But again, the evidence is all but conclusive that there has been recent subsidence;[2] and, indeed, so far as I can see, it is impossible to say whether the last movement was one of elevation or of subsidence.[3] The difficulties attending the solution of this question will be appreciated by all geologists.

The complexities that are involved in the problem of the construction of the Gulf basin are also a part of the history of the adjoining basin of the Caribbean Sea. In their united physiognomy the most distinctive feature is constituted by the deep channels of water which delimit the banks that have been briefly referred to and which are known to geographers as the Straits of Florida and Bemini and the Yucatan Passage. The depth of water in the former, whose width is some 50 miles, is between 2200 and 3000 feet; in the latter, with a width of 80–90 miles, it reaches 1000 fathoms. If we assume the greatest depth of the Yucatan Passage to be at about its middle, and that there is more or less of a regular slope of the bottom leading from either side to this point, the average gradient of the bed would be approximately 1 in 35, or about 150 feet to the mile. Much the same profile would be presented, under a like assumption, by the Straits of Florida. This slope, while it is steep, is not yet so steep that it can in any way be designated precipitous. In fact, an equal deviation from the horizontal in the ceiling of an ordinary room would scarcely offend the eye. If the Yucatan Passage were drained of its water, it would present the appearance of a

[1] The Bermuda Islands: "A Contribution to the Physical History and Zoology of the Somers Archipelago," 1889, pp. 59–61, 73.

[2] As I have stated in my Report on Florida explorations ("Explorations on the West Coast of Florida and in the Okeechobee Wilderness," Trans. Wagner Free Institute of Science, p. 15, Phila., 1887), and as Shaler has also found in the course of his own investigations (Bull. Mus. Comp. Zoology, XVI, p. 148, 1890.)

[3] Only relative movement is here implied; the interesting problem of oceanic transgression and retrocession, which has been so forcibly argued by Suess and others, is not considered in this place.

vast flat in which the eye would barely be able to detect a hollow.[1] Allowing that the deeper water is met with long in advance of the center of the channel, or for a slope of double intensity, the cut would be only in the form of a gently undulating valley, with nothing in it to remind one of a ravine or gorge. I make this comparison because I believe it will serve to a proper understanding of the conditions under which these special physiographic features may have been brought into existence.

The gradual slope—for such it can really be called—of the channel seems to dispose of the *necessity* of invoking (although by no means disproving the condition) the assistance (in the construction of the channel) of either faulting or fracture. At the same time I believe it equally disposes of the notion that the channel has been primarily formed through the scour of the Gulf Stream, as has been maintained by Alexander Agassiz; at least I see no grounds for believing that it has been so formed, and the fact that the pitch of the floor-bed is much less than it is (between the 500 and the 1000 fathom contours) along much of the adjacent continental borders where no currental scour of any magnitude is known argues against the supposition. The undulation that is present, and concavities of which form the two channels under consideration, is no greater than that which ordinarily exists over any broad plain or mesa surface of the continental areas.

That the Gulf Stream may now be to a certain extent deepening these channels is possible, but this is hardly likely to be the case. Even if it be held, as the observations of the "Blake" seem to make clear, that "the bottom of the Gulf Stream along the Blake Plateau is swept clean of slime and ooze, and is nearly barren of animal life,"[2] this fact does not necessarily argue in favor of scour, since just in the path of the most rapid current of this stream, in the Straits of Florida, where the flow is from four to five miles an hour, the researches of Pourtalès, A. Agassiz and Murray have revealed the presence of vasts deposits of ooze. It is further a suspicious circumstance, seeing that we have no evidence of the much greater antiquity of one channel over the other, that the Yucatan Passage, in which the flow is barely more than a fourth of a mile per

[1] The actual slope of the channel's bed is not as regular as has been assumed in the above proposition, but for all practical purposes, I believe, the comparison will hold.

[2] "Three Cruises of the Blake," I, p. 259.

hour, should have a depth double that of the Florida Straits, in which the rate of flow, as has already been seen, is four miles an hour, and more. The stream with a relative velocity of 16 has excavated a channel with but half the depth of that excavated by a stream whose velocity is only 1. Of course, modifying circumstances may to a considerable extent lessen the disproportion of action, but not sufficiently to lend any probability to the theory of Gulf scour.

It is now, I believe, a widely recognized fact that the peninsula of Florida has in quite recent geological times, even so late as the newer Tertiary or Post-Pliocene, been united with the greater Antilles (or at least with Cuba) and the Bahamas into one more or less continuous land-area; the evidence, at any rate, for this supposition is of such a nature that it cannot readily be explained away.[1] And I believe it scarcely less probable that this connection was continued quite to the peninsula of Yucatan, although the separation there may have begun at a slightly earlier period. But it will be asked, if the separating channels have not been formed either through dislocation (fracture) or the wear of the Gulf Stream, in what manner has the existing disruption been brought about? I think that the theory of subsidence offers the easiest and the most plausible solution to the problem. But the theory, to be worthy of confidence, must have some facts to support it, and it behooves us to inquire if any such exist. As to a limited subsidence within a very recent geological period (Post-Pliocene)—sufficient, probably, to account (if this were necessary) for the positions of the several atoll-like reefs which have been cited by the opponents of the Darwinian theory of reef-structures in evidence against subsidence[2]—there is ample testimony. With regard to the region of the Floridian peninsula, I have stated some of the facts in the Report before referred to, and Prof. Shaler has since the time of my explorations obtained new data supporting the conclusion I had arrived at.[3] On the Yu-

[1] DeCastro, Bolet. Com. Geol. Esp. VIII, pp. 357–72, 1881; Dana, "Origin of Coral Reefs and Islands," Am. Journ. Science, 3rd Ser., vol. XXX, 1885; Suess, Antlitz der Erde; Heilprin, "The Bermuda Islands," pp. 227–28.

[2] I fail to see in what way the Alacran Reef, on the Yucatan Bank, is a true atoll.

[3] The Topography of Florida—Bull. Mus. Comp. Zoology, vol. XVI, 1890. Heilprin "The Corals and Coral Reefs of the Western Waters of the Gulf of Mexico," Proc. Acad. Nat. Sci. Phila., 1890, p. 314.

catan side the evidence is, I believe, equally conclusive. The deep hole of Bolonchen, to which reference has already been made, can reasonably be explained, if the measurements of Stephens are at all to be relied upon, only on the assumption of subsidence. The condition of some of the other caves seems also to argue in the same direction. On the north shore the solid limestone at many places abuts directly against the Gulf waters, or is even carried into them, as I had occasion to observe near the Port of Silam, in scattered ledges and boulders. I was also informed that in the course of construction of the long pier at Progreso, masses of rock, similar to that which is found inland, were met with at various points off from the coast. Of course, the same conditions might be presented by a rising surface the moment we admit that a consolidated limestone—except such as coral and oyster reefs, etc., which are colonial accumulations or out-growths—may be formed *in extenso* beneath the water of the sea. I am not aware that a structure of this kind has as yet been definitely proved to exist. It is true that A. Agassiz asserts that he not infrequently obtained, by means of the trawl or dredge, "large fragments of the modern limestone now in process of formation,"[1] but I do not precisely see how this limestone, "consisting of the dead carcasses" of species now living in the Gulf, would be differentiated from a limestone which had been placed in the same position through subsidence.

But granting the full value of the evidence favoring subsidence, the amount of subsidence itself is not sufficient to account for the existence of the deep water between Florida and Cuba, and still less for that between Cuba and Yucatan. Prof. J. W. Spencer, in a recent and very suggestive paper on "High Continental Elevation preceding the Pleistocene Period,"[2] has brought together a number of facts, drawn largely from the condition of the (supposed) ancient estuaries of several of the American rivers, which, in the opinion of the author, go far toward indicating a very considerable subsidence along the American coast, and it is well to inquire into the relation which this (assumed) subsidence may hold to the problem under consideration. The deep submarine channels (or what are taken for them) of the Mississippi, Delaware, Hudson and St. Lawrence Rivers, which cut into the 90–500 fathom curves, are taken in part as evidence of this submergence; on the Pacific side we

[1] "Three Cruises of the Blake," 1, p. 62.

[2] Bulletin Geol. Soc. America, 1, p. 65, *et seq.*

have the testimony of the deep submarine valleys which Prof. Davidson has described from the coast of California,[1] and the fjords and friths of Washington and British Columbia.[2] While it may not be admitted that all of the above deep cuts are really old channels, geologists are more generally agreed that the one which has been so minutely traced by Lindenkohl south of Long Island is the true channel of the Hudson River,[3] which terminates at about one hundred miles southeast of the present coast line, at a depth of 2800 feet beneath the level of the sea (or 2200 feet beneath the surface of the plain or plateau into which the trough is cut). It is wholly improbable that this channel could have been formed in the manner in which some geologists have attempted to explain the so-called cañon which continues westward the course of the Congo,[4] or that it is today being cut in the way that Hörnlimann found the rivers Rhine and Rhone cutting into the sublacustrine deposits of lakes Constance and Geneva respectively.[5] But if not thus formed, I do not see that we are necessarily driven to consider subsidence as the only possible explanation of the occurrence; indeed, there are certain difficulties in the way of the emergence-subsidence theory, especially those relating to time, which to me seem almost insurmountable. Prof. Dana suggests as the most likely time for the emergence of the land, which permitted of the cutting of the deep sea-ward channel, the close of the Jura-Trias period (followed by the subsidence which allowed ingress of the Cretaceous waters); Upham, on the other hand, would prefer some portion of the late Tertiary or Post-Pliocene.[6]

[1] Bull. Calif. Acad. Sciences, II, pp. 265–68; see also paper by Prof. LeConte "The Flora of the Coast Islands of California in Relation to Recent Changes of Physical Geography"—Bull. Calif. Acad. Sciences, II, pp. 515–20.

[2] G. M. Dawson: "Note on some of the more Recent Changes in Level of of the Coast of British Columbia and Adjacent Regions"—Canadian Naturalist, new ser., VIII, pp. 241–250.

[3] Dana, Am. Journ. Science, Dec., 1890.

[4] Buchanan, Scottish Geographical Magazine, III, p. 222, 1887.

[5] F. A. Forel. Comptes Rendus, CI, pp. 725–28, 1885. Forel assumes that the deep cutting in the case of the European rivers just mentioned is largely (or almost wholly) due to the fact that the waters of the rivers are considerably heavier than those of the lakes, and thus sink to the bottom, scouring there the surface; but this condition does not hold with the streams discharging into the sea, except in so far as the added weight of sediment will conduce toward sinkage.

[6] American Geologist, September, 1890.

It appears to me improbable that a channel dating back to the Lower Cretaceous period could have remained open to the present time; that a million, or possibly millions of years, should not have effaced the contours of a river cut in a region of heavy oceanic sedimentation is to me incredible. And the more improbable is the condition made, when we see how smoothly the subcontinental plateau has been worn or filled in on either side of the assumed channel. Perhaps less objection can be urged against the view of recent emergence (and subsequent subsidence) which is held by Mr. Upham; the nature of the proposition is, in itself, such that it cannot readily be met by the facts of geology. Mr. Upham bases his proposition upon the concurrent testimony of facts presented by the eastern, southern, western and northern waters,[1] and from these he argues that there has been a simultaneous elevation of the entire continent, and not merely one confined to a section of the northern regions. During this period of high elevation, which is made incident to the formation of the ice of the Great Ice Age, the cutting of the deep river-channels was effected. But it is almost inconceivable that such a general continental uplift could have taken place without materially disturbing the courses of the principal rivers; the barest tilting of the land would almost certainly have changed the course of such a low-plain river as the Mississippi, but the river discharges to-day almost in a line with the excavation which is supposed to represent its former mouth in the Gulf. The same holds true with the Hudson and the Lindenkohl channel. But again, the same difficulty, only intensified, confronts us if we assume localized or regional uplift; and, further, in the event of such uplift, we should look to a much greater deformation of the coast-line than now actually shows itself. Prof. Dana has called attention to one very serious objection to the theory of recent erosion in the form (in depth) of the Lindenkohl channel; the uneroded or even surface of the plateau into which this channel is sunk seems to be to one equally grave.

It must be admitted that many of the difficulties in the case disappear if, instead of an actual rise or emergence of the land, we assume an equivalent recession of the oceanic waters; indeed, the stability of river-courses appears to me a strong argument against the see-saw movements of which continental masses are supposed to partake, and one decidedly in favor of the view of oceanic transgres-

[1] Those principally which have been recited by Prof. Spencer.

sions and recessions which has been so ably formulated by Prof. Suess and the new school of German geologists. But the removal of a difficulty is not a proof of a proposition; and I do not know that there are any facts to indicate that there has been a comparatively recent recession of the oceanic waters, beyond the continental boundaries, to an extent of 3000 feet (vertical). On the contrary, the regular succession of the Tertiary deposits along the eastern and southern borders of the United States, completing the series near the extremity of the Floridian peninsula, and the regular gradation of the animal forms which are contained in this series, seem to me to point to an opposite conclusion.

But even if we admit all that the advocates of river-erosion claim for these submarine channels, I think it still remains an open question if all the phenomena are referable to a single cause. Similarity of physiographic feature is no necessary indication of equivalency in the time of formation or equivalency in method. The deep cut of the ancient Mississippi (or what is referred to as such by Spencer and Upham) occurs at about the 500 fathom curve, whereas that of the so-called Hudson River Channel marks the 80–100 fathom line. On the theory of river-erosion the formation of the Mississippi cut, if we once admit subsidence, need not have necessitated an elevation of the land of more than 1200 hundred feet—perhaps not that much—as against the 2200 required by the Hudson Channel. That the Mississippi cut was not formed at or about the close of the Jurassic period is practically proven by the coincident position of the present mouth of the river; it is all but inconceivable that a stream should find its way to an ancient mouth after 600 miles of its lower course (as is shown in the Cretaceous Mississippi embayment) had been obliterated by the encroaches of the sea. The objections to its having been formed at a recent period of great elevation have already been stated; the remarkable evenness of the Florida Plateau argues strongly against any recent upheaval of some 3–4000 feet.

I believe that the occurrences presented near the mouth of the Mississippi have little or nothing in common with those of the Hudson; they constitute a part of the physics of the Gulf of Mexico as distinguished from those of the North Atlantic. Suess[1] and Seebach[2] have forcibly sketched the relations of the West Indian Is-

[1] Antlitz der Erde, I, p. 698, *et seq.*

[2] Central Amerika und der interoceanische Canal, 1873.

lands and of the mountain chain or chains which traverse the larger Antilles; the parallel drawn by the former between the Caribbean Basin and that of the Western Mediterranean,[1] apart from other evidence, leaves little doubt in my mind that it partakes largely of the structure of the latter—*i. e.*, it is a sunken area of the earth's crust, which has carried with it fragments of a once continuous or nearly continuous system of mountain elevations. Parts of this mountain system can still be seen in the chain of heights (reaching an elevation of 9,000 feet, or more,) which traverses Porto Rico, the islands of Hayti, Jamaica and southeastern Cuba, pointing to continuations in Honduras and Guatemala. The similarity of the rock-formations in these different islands (with those of St. Bartholomew, Antigua, etc.) points to a community of origin, if not necessarily to continuity, but we have, it appears to me, abundant evidence of continuity—extending as far as Florida on one side and to Central America and South America on the other—in the relationship of the existing molluscan fauna of these islands, as has been shown by Bland,[2] and in that of the extinct mammalian faunas, for the elaboration of which we are indebted to the labors of DeCastro, Cope, Pomel and Leidy.[3] The conformation of the sea-bottom, as the soundings of the "Blake" have made known to us, also indicates this connection. It is probable that the disruption or subsidence, or series of subsidences, which resulted in the existing condition of region did not set in until the close of the Miocene or beginning of the Pliocene period—perhaps not until still later—as the distribution of the extinct mammalian fauna shows. What the area of this subsidence may have been it is not easy to determine, but it with little doubt included the whole of the region of the Bahamas, and probably much more to the north. From considerations other than those that have been stated, Alexander Agassiz has arrived at the conclusion of a vast change of level in the subcontinental plateau lying east of the southeastern coast-line of the United States, for he inclines to the belief that this coast-line, opposite to what is known as the Blake Plateau, at one time extended seaward approximately to what is now the position of the 500-fathom line.

[1] *Op. cit.*, I, p. 708.

[2] Annals Lyceum Nat. Hist. New York, VII, pp. 335–61; X, pp. 311–24.

[3] DeCastro, *loc. cit.*; Cope, Proc. Acad. Nat. Sci. Phila., 1868, p. 313; Smithsonian Contributions, 1883 (1878); Leidy, "Mammalian Fauna of Dakota and Nebraska," 1869.

To quote the language of this distinguished investigator: "In other words, the old continental line extended at least two hundred and fifty to three hundred miles farther to the eastward, forming a huge plateau, the hundred-fathom line of which was found where the six-hundred-fathom line now runs, and stretched as far south as to include the Bahamas and Cuba in this great submarine plateau."[1] It is true that Agassiz recognizes in the lowering of the Blake Plateau—which he considers to be a special formation organically built up from the deep, and added to "the outer edge of the former continental plateau"[2]—no evidence of subsidence, but merely the wearing action or scour of the Gulf Stream, whose operations began at about the close of the Cretaceous period. But I can see no facts which support this double conclusion; on the contrary there are many—some of which have already been stated, and others which can be drawn from the physiography of the region lying to the south and southeast—which distinctly oppose it.[3] The character of the Cretaceous deposits pretty clearly indicates that at the time of their formation they were bounded by a deep sea, and that the Blake Plateau could not have been built up until a time much later. The fact that off the coasts of North and South Carolina "small rocky banks slightly raised above the general level of the sea-bottom" occur which seemingly represent "the continuation of the Tertiary beds found inland along the adjoining shores," and that the Gulf Stream for much of its course in this region sweeps over a bottom of "hard limestone"[4] also argues in favor of a late subsidence. Suess with more justice, it seems to me, argues that the base of

[1] "Three Cruises of the Blake," I, p. 136.

[2] *Loc. cit.*

[3] I am not absolutely certain as regards Agassiz's explanation of Gulf Stream wear. While on pp. 137 and 138 the course of the stream is very definitely traced, from the close of the Cretaceous period, in a northeasterly direction across what is now the peninsula of Florida (or through the Straits of Florida) and the Blake Plateau, we find on page 113 that a similar stream, at about the same time (or even later?), may have swept "round the north end of the Bahamas across Florida, which did not then exist, across the Gulf of Mexico, and into the Pacific over the Isthmus of Tehuantepec."

[4] A. Agassiz. *Op. cit.* p. 277.

the Bahamas is a Miocene rock,[1] and for anything we now know to to the contrary, the reef-structures may be imposed upon a Pliocene formation.

While perhaps we have no positive knowledge in the premises, I think it more than probable, following Suess,[2] that the Gulf of Mexico represents a subsiding basin similar to the Caribbean Sea, and here again a parallel can be established with the eastern basin of the Mediterranean. The close approximation of the 500, 1000 and 1500 fathom lines off the western borders of the Florida and Yucatan plateaus seemingly points to such subsidence, and it suggests, as, indeed, Suess has already intimated, that the breakage actually took place through the Florida-Yucatan Plateau. That the Mexican waters already existed as far back as the Cretaceous period is abundantly proved by the Cretaceous deposits which extend throughout the Gulf area, but it would seem that the great depth which the basin now has was acquired at a comparatively recent geological period, much of it probably at a time when many of the larger Mammalia which now inhabit the land-surface had already been introduced, and long after the Mississippi discharged near to (or in advance[3] of) its present mouth. Perhaps the absence over the greater part of the Gulf area of the newer Tertiary deposits which occur elsewhere along the southern United States may be explained on the assumption of disappearance through subsidence; at any rate, their non-existence is a suggestive fact.

To what extent the assumed subsidence of the Gulf basin may have been connected with volcanic phenomena, or have been induced through sedimental accumulation, as Prof. Shaler suggests, cannot, with our present knowledge, be determined; probably both forces have acted toward a common result.

Just as we look upon the Gulf and Caribbean basins as subsided areas, so may we regard the Yucatan and Florida Passages, and to

[1] Antlitz der Erde, II, p. 161. On the island of Antigua the rock containing *Orbitoides* dips beneath the sea. Since the above was written, it has been shown that the Oligocene deposits (containing *Orbitoides*) of southeastern Florida extend down to a depth of at least 1200 feet; the data were obtained from a boring made at Lake Worth, east of Lake Okeechobee (Darton, in Am. Journ. Science, Feb. 1891).

[2] Antlitz der Erde, I, p. 365; II, p. 159.

[3] The position of the supposed ancient channel.

[4] The Topography of Florida, Bull. Mus. Comp. Zoology, XVI.

approximately the same period of time can we assign their formation. That actual movements have taken place in the region under consideration at a quite recent period is proved by the uplift of the Yucatan mountains,[1] which, as has already been stated, belong with little doubt to the Pliocene period.

[1] Prof. Shaler has suggested that possibly the Florida plateau has been in part squeezed up through the downfall of the Gulf basin. With a subsiding area on either side of it (repeated again in the case of the Yucatan plateau) this does not appear improbable, and perhaps the gentle axial fold of the peninsula is evidence of this compressional uplift.